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review

High-Strength Steels

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UNIDIRECTIONALLY SOLIDIFIED WROUGHT STEEL ARMOR

Wrought-steel armor plates produced from unidirectionally solidified castings performed better than conventionally processed homogeneous armor plates and compared favorably with commercial dual-hardness armor in ballistics tests, according to U.S. Steel.(1) The plates were produced from 240-pound experimental castings with a nominal composition of 0.6C-1Ni-0.5Cr-0.5Mo. The castings were homogenized at 2400 F for 64 hours, and rolled to 3/4-inch-thick and 1/2-inch-thick plates which then were heat treated to a hardness of 555 BHN. The best 3/4-inch-thick plates resisted complete penetration by 0.50 AP caliber projectiles. Although the 1/2-inch-thick plates were completely penetrated by the projectiles, they did not crack or back spall. By comparison, the investigators reported that the hardness of conventionally processed homogeneous steel armor must be kept below 535 BHN to prevent cracking or back spalling.

TEMPER EMBRITTLEMENT OF ALLOY STEELS

Certain alloy steels exhibit an embrittling effect after they have been heated to temperatures within or slowly cooled through a critical temperature range normally from about 1100 F to 750 F. Temper embrittlement has been a serious problem, particularly in large sections which cool very slowly from their heat-treatment temperatures or after stress relieving. Although the mechanism of temper embrittlement is not completely understood, several theories have been proposed to explain the phenomenon. These theories can be divided into three basic groups on the basis of (1) austenite grain-boundary precipitation, (2) segregation to austenite grain boundaries, and (3) dislocation locking by precipitates or atmospheres of solute atoms.

Two studies which provide data to illustrate that there is more than one mechanism of thermal embrittlement of high-strength steels have been reported. One of these studies evaluated susceptibility of a candidate HY-180 steel to temper embrittlement as a function of impurity elements (antimony, phosphorus, tin, and arsenic).(2) The other evaluated the effects of thermal and thermomechanical treatments on the temper embrittlement of low-alloy engineering steels.(3)

In the study of the susceptibility of the 10Ni-2Cr-1Mo-8Co steel (a candidate HY-180 steel) to temper embrittlement, the antimony, phosphorus, tin, and arsenic contents were varied.(2) The steel did not exhibit significant embrittlement, regardless of heat treatment, when antimony was present in amounts less than 0.020 percent, when arsenic was present in amounts less than 0.047 percent, when tin was present in amounts less than 0.008 percent, or when phosphorus was present in amounts less than 0.017 percent. However, at higher levels of these elements, embrittlement was observed with long-time holds in the temperature range 850 to 950 F, but only antimony (0.075 percent) caused temper embrittlement during the conventional aging treatment, which consists of holding at 950 F for 5 hours. The embrittlement caused by these impurity elements resulted in intergranular fracture along prior austenite grain boundaries. Further analysis showed some precipitates at the grain boundaries, but the investigators speculated that the embrittlement was primarily caused by adsorption of the impurities at grain boundaries and the resultant loss of adhesion at the grain boundaries. With the normal level of impurities present in this steel, temper embrittlement was concluded to offer no problem. The influence of rapid heat treating and ausforming on temper embrittlement of British alloys En 30B and En 40C has been studied by the British Steel Corporation.(3) Both treatments result in the refinement of the structure of these low-alloy steels; and hence, would be expected to minimize temper embrittlement if it were primarily a grain-boundary phenomena. From this study, the investigators proposed an embrittling mechanism based on the precipitation of coarse carbides (intragranular and intergranular) and on pinning of dislocations resulting in high-dislocation densities. They also showed that temper embrittlement can result in transgranular fracture. Therefore, intergranular fracture, which is often considered the criterion for temper embrittlement, is not synonymous with this phenomenon. In addition, experiments with En 30B which contained high sulfur and phosphorus contents showed that segregation of these elements in the prior austenite grain boundaries can lead to embrittlement resulting in intergranular failure. The investigators emphasized that several mechanisms can result in temper embrittlement of low-alloy steels and that, in general, they are embrittled as a result of the interaction of two or more of these mechanisms. The relative predominance of one mechanism over the other depends on the composition and on the thermal and mechanical history of the steel.

THERMAL GRAIN REFINEMENT OF 18Ni (300) MARAGING STEEL

A method of refining the grain size of coarse-grained 18Ni (300) maraging steel by thermal cycling has been reported by Wright-Patterson Air Force Base.(4) The process consisted of heating the steel to the 1800 to 1900 F temperature range and cooling to below 200 F; the optimum temperature for refinement was 1880 F. The heating and cooling rates were reported to be of minor importance. In this study a treatment consisting of 3 cycles reduced the grain size from ASTM 0 to ASTM 7; additional thermal cycles did not reduce the grain size further. A single cycle reduced the grain size from ASTM 0 to ASTM 4 with some finer grains interspersed in the structure. Although much finer grain sizes (ASTM 12 and smaller) have been produced by plastic deformation-recrystallization methods, the investigators suggested that the thermal cycling treatment could be used by processors encountering coarse-grained maraging steel in components in the finished shape to obtain a grain size of ASTM 7 and possibly somewhat improve fracture toughness and stress-corrosion resistance.

INCLUSIONS IN HIGH-STRENGTH STEEL

Additional data have been reported on two programs directed toward relating the effects of inclusions, detected by ultrasonic inspection of billets, with the mechanical properties of AISI 4340 steel heat treated to the 280 to 300 ksi strength range.(5,6) Although different ultrasonic systems and inclusion rating systems were used, both programs showed a correlation between the ultrasonic inclusion ratings and the mechanical properties of the steel. Both studies showed that reduction of area was most adversely affected by increased inclusion contents and that the fatigue properties were also significantly reduced by increased inclusion contents. The fracture-toughness properties (Charpy V notch and K_{IC}) of the steel were much less sensitive to the inclusion content; however, there was a general decrease in toughness with increasing inclusion content.

One of the studies indicated that stringer-shaped alumina and aluminates were most detrimental to the fatigue properties; rounded shapes were second, while sulfides did not appear to be important in nucleating fatigue failures.(6)

EUROPEAN LITERATURE SURVEY

Battelle-Frankfurt surveyed the European literature on stress-corrosion cracking and hydrogen-stress cracking of high-strength steels for DMIC. Most of the information found originated from American sources, and very little work outside the United States was found. However, there is continual and growing interest in high-strength steels in European countries, and in the future, publications in this area could be expected to reflect new studies rather than the results of American research.

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